XIX. *On certain new Phenomena of Colour in Labrador Felspar, with Observations on the nature and cause of its Changeable Tints.* By David Brewster, LL.D. F.R.SS. L. & E.

(*Read May* 20. 1829.)

Sir Isaac Newton's theory of the colours of natural bodies, is perhaps the most ingenious and lofty of all his speculations. It was devised, however, at a time when the doctrine of light had made comparatively but little progress, and before the discovery of various principles on which the colours of bodies must depend, or by which, at least, they must be extensively modified. The different dispersive powers of transparent substances;—the irrationality of the spectrum;—the action of striated surfaces;—the decomposition of polarised light;—the reflection of coloured light at the confines of equally refracting media;—and the absorption of common and of polarised rays,—are principles which embrace within their individual range a great variety of facts to which the Newtonian theory of colours bears no relation. In that theory, indeed, we recognise more the flight of a transcendant genius, than the patient and anxious step of inductive research; and so firmly has it entrenched itself among the strongholds of modern science, that no regular attempt has been made to unsettle it, or even to submit to a rigorous analysis the various phenomena of colour, as displayed in mineral and vegetable bodies, and in the artificial combinations of the laboratory. Such a task I should not have presumed to undertake; but in the course of an extensive examination of minerals, the subject has been forced upon my attention, and having extended the inquiry to vegetable bodies, as well as to chemical combinations, I pro-

Fig. 1.

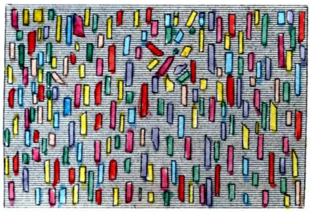


Fig. 2.

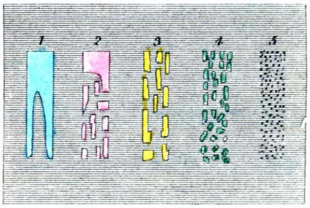


Fig. 3.

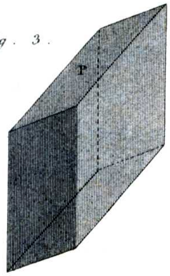


Fig. 4.

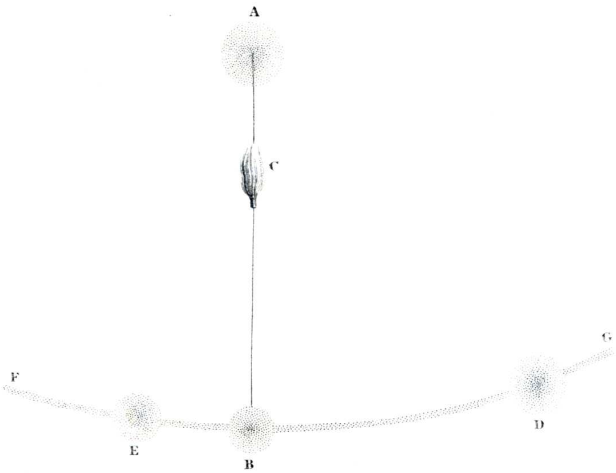
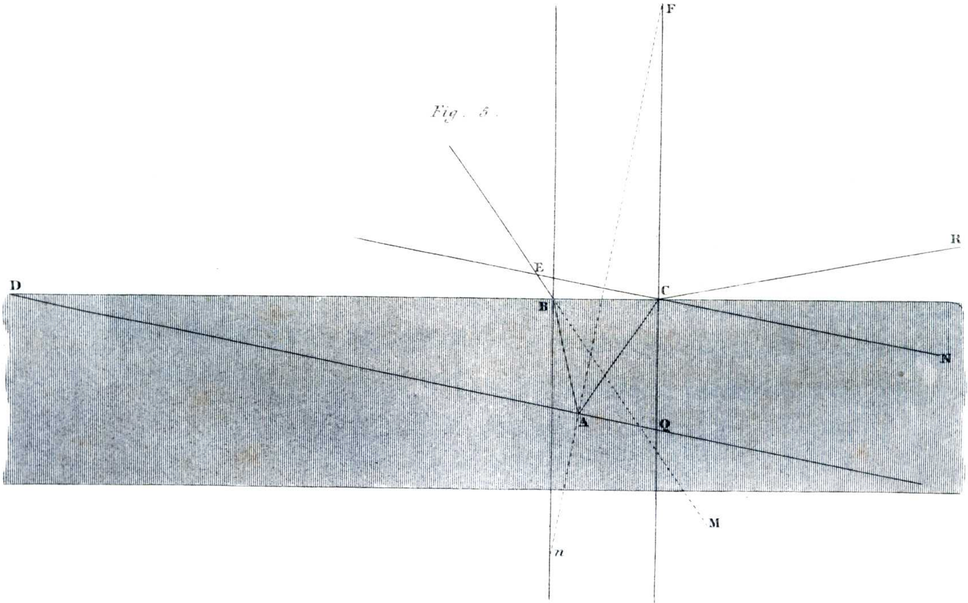


Fig. 5.



W. H. Lizars sculp.t

pose, in a series of papers, to submit the results to the Royal Society.

In my account of the Cavities in Topaz, and other minerals, I have mentioned the frequent occurrence of strata of cavities, so minute that they are scarcely capable of being resolved by the most powerful microscope. In the larger cavities, their depth is sometimes very small, compared with their other dimensions; but in the more minute pores, as they may be called, there is a greater equality in their length, breadth, and thickness, and I have never been able to recognise any thing like the colours of thin plates reflected from the strata which they compose.

In seeking for the new fluids in Labrador felspar, the fine changeable tints of that mineral could not fail to excite particular attention; and after examining some specimens, I discovered a new set of colours, which seemed to be capable of a distinct analysis. When these colours are seen by a microscope, and under strong illumination, they form a highly beautiful phenomenon, somewhat resembling Fig. 1. Plate XIII.

The coloured portions have the form of parallelograms, sometimes complete, sometimes truncated at the angles, and sometimes so rounded as to have no regular outline. Their longest sides are generally parallel to one another, and they are sometimes arranged in groups, with their homologous lines in different directions. The parallelograms are not distributed in a single stratum. They appear at different depths; and those which are much below the surface have little brilliancy, owing to the imperfect transparency of the mineral. These coloured spaces vary from the 40th or 50th of an inch in length, to the most minute point which the microscope can descry.

The tints reflected from these spaces are generally very brilliant. They are sometimes white, and sometimes all of one colour, but I have never found them below the blue of the second order of NEWTON'S scale. The surface which reflects them, generally displays throughout the very same tint; but in some cases, the same parallelogram exhibits different colours at the same angle of incidence, owing sometimes to the mixture of the tints of superposed parallelograms, and sometimes to the variable thickness of the space by which the colours are occasioned.

The parallelograms which produce the colours now described, may be crystallized laminæ disseminated through the felspar, and giving the colours of thin plates; or they may be slender crystals, which, like the veins of calcareous-spar, develope the tints of polarised light; or they may be crystallized cavities, either entirely empty, or containing solid, fluid, or gaseous substances.

The exceeding toughness of the mineral renders it impracticable to obtain good cleavage planes, passing through the parallelograms, for the purpose of shewing their interior, or of discharging their contents, as I succeeded in doing while examining the topaz cavities, so that I had no other resource but that of optical analysis.

As it was necessary to examine the light transmitted through the parallelograms, I detached a very thin splinter from the mineral, and placed it in Canada balsam * between two plates of glass. It was so thin at one edge, that it did not give the colours of polarised light, and at its greatest thickness, it developed only the *red* of the third order. It had fortunately only one stratum of parallelograms, so that their reflected and transmitted tints could be observed with the greatest distinctness. The reflected tints were uncommonly brilliant and pure, but the transmitted ones were very faint, and of a yellowish, reddish, or greenish-brown colour, varying with the obliquity of the incident ray. I now placed the splinter on the base of a prism, with Ca-

* Oil of Cassia would have been preferable in other cases, but as it has a colour of its own, and disperses light so powerfully, it was unsuitable where delicate tints were to be observed.

nada balsam interposed, and I found that the tint diminished as the angle of incidence increased, and that the same effect took place in the same degree in all azimuths. This experiment proved incontestibly that the colours were not those of polarised light. That the cavities do not contain a gas or a fluid of any kind, is obvious from the fact, that the felspar does not decrepitate or burst with heat. Hence, it follows, that the parallelograms must be either empty, or must contain indurated matter.

In order to ascertain, upon the supposition of the parallelograms being solid, whether the colour arose from the thinness of the solid matter, or from the thin open space which separated the surface of the parallelograms from the adjacent felspar *, I observed the particular tints which a number of individual parallelograms produced at a given incidence; and upon reversing the specimen, I found, that, in every case, the very same tints were developed at the same angle of incidence. This result clearly proves, that the tints were due to the thickness of the cavity, whether they were empty or filled with indurated matter.

The examination of individual parallelograms presents some instructive peculiarities. While the greater number give an uniform uninterrupted tint, several have the appearance shewn in Fig. 2. In No. 1, the parallelogram is imperfect. In No. 2, it is more so, though the individual patches of colour fill up its outline. In No. 3, they are smaller still, and more unequal. In No. 4, we can still discover the outline of each individual patch; but in No. 5, the patches are so minute, that the surface of the parallelogram produces all the variety of mottled colours. These phenomena indicate a general resemblance to

* It is from this cause that the splendid colours arise which accompany the dendritic crystallizations of titanium in mica, which I have examined with much attention.

indurated matter, but, when minutely examined, this resemblance disappears. The spaces between the individual patches are in almost every case dark, like the adjacent felspar; and when the microscope is capable of separating the individual patches, it becomes quite obvious, that, if they are grains of indurated matter, they are not disseminated through an empty cavity, but are imbedded in the felspar. We have no hesitation, therefore, in concluding, that all these little patches and specks of colour are empty cavities, like the large parallelograms, for the intensity of the light reflected from the small patches in Nos. 3, & 4. of Fig. 2, is the same as that reflected from the parallelograms. This light, indeed, is so strong, that nothing but a metallic substance filling the cavities, and in optical contact with their sides, could reflect it. If this were the fact, the analysis of the mineral could not fail to exhibit it, and I am not aware that any metallic ingredient, except titanium, has been detected in felspar. M. Peschier has announced this fact, but whether it was found in common Felspar or Labradorite, I have not the means of ascertaining. Professor Rose of Berlin, however, who carefully analysed the Labradorite of various localities, has not been able to discover any such ingredient. But even if titanium were a constant element of Labradorite, the parallelograms could not contain that metal; for I have ascertained that titanium in optical contact with mica reflects much less light than the parallelograms; and since mica has a refractive power greatly inferior to felspar, titanium in optical contact with felspar, will reflect much less light than in contact with mica, and consequently much less light than the parallelograms.

Having thus determined that all the colours under our consideration are those of thin plates produced by minute cavities within the mineral, varying in magnitude from the 40th of an inch down to the most minute speck which the microscope can descry, we are entitled to refer the other phenomena of colour in the same mineral to similar cavities, though we are no longer able to see their individual outline, or to recognise them in any other way but by their united influence.

The coloured parallelograms above described are, in general, parallel to the face P, Fig. 3, of the primitive form, as given by Haüy; and in no specimen which has come under my examination, have I ever found them coincident with the plane of the common changeable colours which have been so long admired in Labrador Felspar. The largest generally occupy one plane; but I have found another set arranged in another plane, while others have their reflecting edges in a variety of different positions. This effect will be understood from Fig. 4. which represents the images reflected from all the different colorific planes in a specimen in my possession. When we look into the specimen, we see the image C of the candle formed by the ordinary polished surface cut at random. Let the felspar be now turned round till AC, the line joining the candle C, and the great mass of changeable colour A is in the plane of reflection, A being seen by rays incident at a greater angle than C. When this is done, we shall see a series of nearly coincident coloured images of the candle at D, which are the reflections from the parallelograms shewn in Fig. 1. At E, there is another set of nearly coincident images, fainter and less coloured than those at D. At B there is a third set, but they are still fainter and more indefinite. Through these three sets of images there passes an arch of reddish-brown light, extending on each side towards F and G, and formed by minute needle-shaped cavities, which being nearly of equal diameter in every direction except their length, must reflect light in whatever direction it is incident, provided it fall nearly in a plane perpendicular to their length.

We come now to the examination of the changeable colours of the spar, which, so far as I know, have never been submitted to a physical analysis. So little attention, indeed, have they excited, that Haüy, Mohs, and other writers, describe them as lying in planes parallel to the faces of cleavage; and in this circumstance Haüy finds an easy explanation of their origin, by ascribing them to accidental fissures between the natural joints of the mineral *.

Although Labradorite abounds in fissures, I have never discovered any parallel to the general plane of changeable colour, and I possess a specimen in which the colours lie in various curve planes, cutting, at a great angle, all the natural joints of the crystal.

The first point which I was desirous of determining, was the position of the plane of changeable colour. For this purpose, I effected a tolerably good cleavage parallel to P, Fig. 3, and having placed the crystal on the goniometer, I turned it round in azimuth till the white image reflected from the face of cleavage, and the mass of coloured light from the plane of changeable colour, were both in the plane of reflection, the latter being formed by rays nearer the perpendicular. Let the surface of cleavage P, Fig. 3, be represented by DC, Fig. 5, and let RC be a ray of light from a candle incident at C. This ray will be refracted in the direction CA; and if CDQ is the inclination of the plane of changeable colour, the refracted ray CA will be reflected at A in the direction AB, and will emerge from the spar in the direction

* Elles proviennent, comme dans l'opal, des legeres fissures qui interrompent le tissue de la pierre; mais l'opale etant fendillée dans toutes sortes des directions, presente des reflets qui se succedent, à mesure qu'on la fait mouvoir, au lieu que dans le feldspath, dont les fissures coincident sur un seul plan; en sorte qu'ils se montrent tout entiers, lorsque la lumière est reflechie par ce plan, sous l'angle favorable pour la renvoyer à l'oeil, et disparoissent, des qu'on donne à la pierre un inclination differente. J'ai reconnu en observant un morceau de feldspath opalin de Norwege, qui m'a été envoyé par M. Esmark, que les plans d'ou partoient les reflets dont je viens de parler, etoient dans le sens des faces T qui sont les plus etendues.—*Traité de Mineralogie*, tom. ii. p. 613.

BE. The eye at E will therefore see the reflected image of the candle in the direction ECN, and the mass of coloured light reflected at A, in the direction EBM. By measuring the angles, I found that when FCR was $78\frac{1}{2}°$, the angle NEM, or the distance of the coloured image from the common image, was 57°. Calling this distance D, and making m the index of refraction for felspar, A the angle of refraction at C corresponding to the angle of incidence I or FCR, and B, the angle of refraction for a ray EB incident at B (which is equal to the angle of incidence ABn, when the ray passes out of the felspar), and x the inclination of the plane of colour, or CDQ, then we shall have

$$\sin A = \frac{\sin I}{m}, \qquad \sin B = \frac{\sin I - D}{m},$$

and

$$x = \frac{A - B}{2} *.$$

which will give 10° 52′ for the inclination of the plane of colour to the face of cleavage P, Fig. 3. The common section of these two planes nearly bisects the acute angle of the face P.

The changeable colours of felspar generally vary from the *blue* to the *red* of the second order. In the same specimen, the tint frequently shades off at the edges to the blue of the second order; and when we view it at an oblique incidence, by cementing a prism on the polished surface, they diminish from the maximum tint to the *blue*, and sometimes to the *purple* of the second order. The colours are not produced by a single plane,

---

* The demonstration of this is very simple. Through C and B draw Bn, and FCQ perpendicular to DC, and through A draw AF perpendicular to DQ, and meeting Bn in n. Then x = CDA = AFQ = AnB, and BAF = ABn + AnB = B + x. But FAC = ACQ — AFC; consequently, since FAC = BAF, and ACQ = A, we have

$$BAE = B + x, \text{ and } BAE = A - x. \text{ Hence,}$$

$$B + x = A - x, \text{ and } x = \frac{A - B}{2}.$$

but by an infinite number; and when we chip off the smallest fragment, it gives the same colour as the thickest mass. If we have been successful in obtaining an extremely thin edge, we shall find that the brightness of the tint suffers an evident diminution, though the colour itself never changes; and at the very edge of the splinter, we can descry, with a good microscope, the individual specks from which the colour is reflected.

We have already seen, that the light transmitted through the coloured spaces in Fig. 1, does not exhibit distinct complementary tints; and the same indistinctness takes place in the light transmitted through extremely thin splinters that give the changeable colours. But when the spar is the 10th or 20th of an inch thick, the transmitted complementary tint is exceedingly distinct, and, by varying the incidence, it changes from yellow, the complement of the *blue* of the second order, to *blue*, the complement of the *red* of the second order.

Many of the larger cavities, which have a distinct outline, reflect a *white* tint, or a mixture of all the prismatic colours, an effect analogous to the white reflections of the Moon-stone, or *Feldspath nacrée* of Hauy. "Some lapidaries," says Haüy, "give the name of *Argentine* to specimens of this variety whose pearly reflections, in place of proceeding from the interior, emanate from the surface, as in pearls *." The effect here described I have examined in a specimen from Norway, but the light certainly proceeds from the interior, though, from the imperfect transparency of the mass, it appears to a careless observer to be produced at or near the surface. In this specimen, the white light is reflected from planes parallel, or nearly so, to one of the cleavage planes; while in another face of cleavage, we observe an infinite number of small coloured specks of irregular outline pervading the whole of the specimen, but all parallel to one another, and inclined to

* *Traité*, tom. ii. p. 606.

the cleavage plane. The pearly light reflected from this specimen seems to be owing to a want of homogeneity in the mineral, in virtue of which portions of different refractive densities are in contact. The existence of such a structure is clearly proved by the great nebulosity that accompanies the images of luminous objects, and by the dimpled surface of its cleavage planes, when examined by the microscope. This variety of felspar differs as widely from the common Labradorite, as Chalcedony does from Quartz, and the distinctive character arising from its heterogeneous structure is as easily appreciated.

In a fine specimen of felspar belonging to Mr Allan, there are, besides the plane of changeable colour, two other planes, which reflect a silvery white light from long and narrow parallelograms. Each of these last planes is formed of portions not accurately parallel to each other, and hence the reflected light is divided into separate masses. These masses are bounded by the prismatic colours, which disappear when the trace of the plane of reflection is parallel to the common section of the reflecting plane and the surface of the specimen, and reach their maximum when these lines are at right angles to each other. Hence, the prismatic colours are produced by the prism of felspar bounded by that surface, and by the plane that reflects the silvery tints. By ascertaining the angle of a prism of felspar which connects the maximum prismatic tints, we obtain the inclination of the reflecting plane to the surface of the specimen.

In many specimens of felspar, I have observed with the microscope minute crystals and very small spheres of a metallic substance, which I have no doubt is titanium, and which has probably given rise to the peculiarities of M. Peschier's analysis.